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Efficacy of LEED-certification in reducing energy consumption and greenhouse gas emission for large New York City office buildings

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ABSTRACT

In this paper 2011 energy consumption, green house gas (GHG) emission, and ENERGY STAR *Energy Performance Rating* (EPR) data for 953 office buildings in New York City are examined. The data were made public as a result of New York City's local law 84. Twenty-one of these office buildings were identified as LEED-certified, providing the opportunity for direct comparison of energy performance data for LEED and non-LEED buildings of the same type, time frame, and geographical and climate region. With regard to energy consumption and GHG emission the LEED-certified buildings, collectively, showed no savings as compared with non-LEED buildings. The subset of the LEED buildings certified at the *Gold* level outperformed other NYC office buildings by 20%. In contrast LEED *Silver* and *Certified* office buildings underperformed other NYC office buildings. The average EPR for the LEED buildings was 78, 10 pts higher than that for all NYC office buildings, raising questions about the validity and interpretation of these EPR's. This work suggests that LEED building certification is not moving NYC toward its goal of climate neutrality. The results also suggest the need to re-examine some aspects of ENERGY STAR's benchmarking tool.

1. Introduction

The *US Green Building Council's* (USGBC) *Leadership in Energy and Environmental Design* (LEED) green building certification label has grown in popularity since it was first introduced in 2000 [1]. For many years it was commonly assumed that a LEED-certified building saved energy, though little performance data were available to confirm this assertion. Early studies of a selected LEED buildings yielded encouraging results. One such study by Rick Diamond looked mostly at Federal Buildings [2]. Another study looked at a group of LEED buildings in the Pacific NW [3].

In 2006 the USGBC commissioned the *New Buildings Institute* (NBI) to study energy use by commercial buildings certified under the LEED new construction (NC) version 2 program. NBI completed their study in 2008 and concluded that LEED certification was, on average, yielding a 25–30% energy savings [4]. That study immediately drew criticism for its methodology both in gathering and analyzing data [5]. NBI made their data available to other researchers for independent analysis, this author being one of them. This author identified three flaws in NBI's analysis, namely (1) that they failed to construct appropriate subsets of non-LEED buildings with which to compare their LEED building data, (2) they focused on site energy rather than primary or source energy, and (3) they failed to appropriately weight for building size in calculating average LEED energy utilization intensities (EUI). Correcting for these flaws this author found that the LEED data assembled by NBI showed no significant difference in the primary or source energy consumed by LEED-certified buildings versus that consumed by comparable non-LEED buildings [6].

Newsham et al. also analyzed the NBI data and, similar to NBI, concluded that, LEED buildings were saving 18–39% energy relative to comparable non-certified buildings [7]. Their main contribution was to develop a systematic method for identifying for each LEED building a companion non-LEED building in the 2003 *Commercial Building Energy Consumption Survey* (CBECS) database with which it could be compared [8]. However, like the NBI analysis, Newsham et al. also focused on site not source energy and used averages that did not take into account building size. Correcting for these two flaws this author duplicated their analysis for one type of building – offices – and again found no significant reduction in source energy use of LEED buildings[1] relative to their companion non-LEED buildings [9].

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[1] Office buildings were the largest class of buildings in the NBI data set and provided the best opportunity for making statistically significant comparisons with non-LEED buildings.

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Since the NBI and NBI-related studies, several groups have published energy studies for other collections of U.S. LEED-certified buildings. A University of Wisconsin group looked at electricity used by 11 LEED NC certified U.S. Navy buildings and found that the majority used more electric energy than the U.S. national average indicated by CBECS [10]. Another group looked at LEED NC buildings in the state of Arizona [11]. They concluded that "Arizona's LEED NC under-perform expectations and national energy efficiency averages."

All of these U.S. studies confirm that some LEED-certified buildings exhibit significant energy savings while others do not. Collectively these studies suggest that LEED-certification is yielding modest savings in energy used on site, but, when off-site losses in the electric sector are included (i.e., source energy), on average, LEED-certification is not yielding significant reduction in building source energy consumption or associated green house gas emission.

This conclusion, however, is tempered by the fact that each of these studies suffers from two important shortcomings. The first is the relative scarcity of energy performance data for both a representative and significant number of LEED-certified buildings. Except for the Navy study, each of these studies obtain data from only a subset of the eligible buildings, and these subsets were not selected randomly but, instead, were "self-selected" by the willingness of building owners to volunteer data. This self-selection process inevitably introduces bias in the results. The 121 buildings in the NBI study, for instance, represented only 22% of the 552 U.S. LEED-certified buildings eligible for the study. Moreover, the NBI data set was "seeded" by starting with buildings from the two earlier studies [2,3] for which results were already known to be favorable to LEED. For the Arizona study data were obtained from roughly half of eligible buildings [11]. Selection bias is not evident in the Navy study, but no data were available for non-electric energy sources – hence the study focused only on electric energy [10].

The second problem arises from the difficulty in finding an appropriate comparison group of non-LEED buildings, i.e., developing a credible metric to be used in evaluating LEED building energy consumption. Building energy consumption is driven by a variety of factors including size, building activity, weather, occupancy, and building hours. For the NBI study, LEED buildings having various principal building activities and constructed in different climate zones were compared with U.S. national averages from the CBECS database which is based on 2003 consumption data. The Arizona study was able to focus on data from a particular climate zone, but still relied on data from the 2003 CBECS data base [11].

The U.S. Environmental Protection Agency's (EPA) ENERGY STAR benchmarking system purports to provide a method for comparing the energy consumption of a commercial building with those of similar activity, adjusting for size, climate, and operational characteristics such as number of employees and building hours [12]. Purchased energy, size, location and operational data for a specific building are entered into ENERGY STAR's *Portfolio Manager* and used to determine an *Energy Performance Rating* (EPR) from 1 to 100 that represents the building's source energy rank as compared with "similar buildings" in the national commercial building stock, as characterized by the (2003) CBECS database. An EPR of 80, for instance, means that the building in question, adjusted for its operational characteristics, uses less source energy than 80% of similar buildings in the U.S. commercial building stock. It is tacitly assumed that if EPR's for all eligible U.S. buildings were calculated the list of such scores would have both a median and mean of 50.

2. Energy benchmark data

Recent energy benchmarking requirements instituted in six U.S. cities have the potential to provide unprecedented building energy performance data useful for understanding the efficacy of various energy efficiency measures, including LEED building certification. These cities are New York, Washington DC, Seattle, Austin, San Francisco and, most recently, Philadelphia. All of these cities have passed local ordinances requiring commercial building owners to annually enter their building data into ENERGY STAR's *Portfolio Manager* and make these data available to the city for tracking progress in meeting the city's commitments to reduce greenhouse gas (GHG) emission.

New York City has made its 2011 energy benchmark data for non-residential buildings over 4645 m^2 (50,000 sf) in size available for public access [13]. The NYC database provides building address, gross floor area, site energy utilization intensity (EUI), (weather-adjusted) source EUI, EPR, total GHG emission, principal building activity, and several other building characteristics for more than 4000 commercial buildings constituting a total floor area of 62.2 million m^2 (670 million sf) in the five boroughs of Manhattan, Queens, Bronx, Brooklyn, and Staten Island. To put this in perspective – the 2003 CBECS database attempts to characterize energy used by all U.S. commercial buildings from data sampled from 5215 buildings which constitute 48.5 million m^2 (522 million sf)! In the NYC database we have 2011 energy data for a similar number of buildings and total floor area concentrated in a 32 km × 32 km (20 mile × 20 mile) region of the country. The comparative value of these data is significant. If buildings in this data set can be identified that are LEED certified this will, for the first time, provide an opportunity to study energy used by a set of LEED-certified buildings that is relatively free of the bias introduced by "self-selection." Moreover, the huge body of data for non-LEED buildings from exactly the same geographic region, climate, and time-frame provides the ideal comparison group.

The USGBC has published a database of all LEED-registered projects world wide constituting nearly 50,000 buildings [14]; 2864 of these are buildings located in New York state. Just over 1000 of the NY LEED projects are listed as confidential with no further identifying information. 775 of the non-confidential projects have NYC addresses of which 257 have completed LEED certification. 126 of these NYC certified buildings are reported to have been certified before January 1, 2011, the beginning of the year for which NYC Energy Benchmarking data were gathered.

The NYC Energy Benchmarking program applies only to non-residential buildings that are 4645 m^2 (50,000 sf or larger). 67 of the 126 NYC buildings LEED certified before 2011 fit these criteria. The LEED "project types" or principal building activities (PBA's) include Commercial Office, Retail, Hotel/Resort, Multi-Unit Residence, Health Care, Restaurant, and K-12. "Commercial office" is by far, the most dominant PBA with 37 of them listed in this group of 67. Another three LEED buildings have no PBA designation – making it possible that they might qualify as office buildings, as well (see below).

The USGBC has a number of certification programs. Of these, new construction (NC), existing buildings operation & maintenance (EB O&M), and core and shell (CS) apply to entire buildings and are expected to have significant impact on building energy and GHG emission. In contrast, the commercial interiors program (CI), available to individual tenants of larger buildings, is not expected to effect total building energy consumption. 28 of the 37 + 3 potential NYC office buildings that were LEED certified before 2011 were certified under the NC, EB O&M, or CS LEED programs.

The 28 LEED-certified buildings in New York City have been cross-listed with the City's Energy Benchmark data to obtain a "match" list of 21 LEED-certified office buildings for which 2011 energy performance data are available. Five of the seven omitted buildings either could not be located in the NYC Energy Benchmarking database or their entries in that database did not include EUI data. The other two omitted building were listed as

Table 1
Each line corresponds to one of 21 LEED-certified office buildings identified in the NYC Energy Benchmarking database (see text). Buildings #22 and #23 listed but not included in subsequent analysis. The EPR is the building's ENERGY STAR *Energy Performance Rating*.

ID	Area		Site EUI		Source EUI		GHG	EPR	LEED Certification	Level	Date
	m^2	gsf	MJ/m^2	kBtu/sf	MJ/m^2	kBtu/sf	Tonne CO_2		System		
1	66,841	719,481	922	81.3	1896	167.2	5009	92	EB:OM v2009	Gold	12/1/10
2	95,880	1,032,057	804	70.9	1,981	174.7	5734		CS 2.0	Gold	10/19/10
3	101,629	1,093,934	683	60.2	2043	180.2	6015	93	EB:OM v2009	Gold	7/13/10
4	82,671	889,875	836	73.7	2180	192.2	5803	81	EB 2.0	Silver	6/14/09
5	13,244	142,554	809	71.3	2197	193.7	838	83	CS 2.0	Gold	3/14/10
6	159,402	1,715,800	920	81.1	2504	220.8	12,438	74	CS 1.0 Pilots Only	Gold	3/7/06
7	105,695	1,137,698	1001	88.3	2504	220.8	8357	81	EB O&M	Silver	1/5/10
8	53,264	573,338	1128	99.5	2506	221.0	4907	79	EB O&M	Certified	6/15/10
9	12,047	129,674	826	72.8	2519	222.1	835	62	EB:OM v2009	Certified	2/15/10
10	11,690	125,836	957	84.4	2529	223.0	946	61	CS 2.0	Gold	8/12/09
11	75,295	810,475	1092	96.3	2632	232.1	6820	82	EB O&M	Certified	2/1/10
12	118,283	1,273,197	1173	103.4	2742	241.8	11,402	86	EB:OM v2009	Gold	8/25/10
13	69,151	744,341	1076	94.9	2842	250.6	6081	70	CS 2.0	Gold	8/30/10
14	33,137	356,686	948	83.6	2922	257.7	2744	75	EB O&M	Certified	3/5/10
15	169,598	1,825,552	1117	98.5	3115	274.7	16,092		EB O&M	Silver	6/12/09
16	97,344	1,047,808	1099	96.9	3192	281.5	9169	87	EB O&M	Silver	5/22/09
17	210,919	2,270,336	1923	169.6	3452	304.4	29,066	80	EB O&M	Certified	7/29/10
18	237,132	2,552,494	1318	116.2	3555	313.5	26,514	71	EB 2.0	Certified	7/18/09
19	160,185	1,724,226	1506	132.8	3835	338.2	20,135	62	EB 2.0	Silver	6/8/09
20	57,826	622,439	1640	144.6	4044	356.6	7882	82	EB 2.0	Certified	12/1/06
21	78,260	842,394	1501	132.4	4181	368.7	9819	73	EB 2.0	Silver	5/19/09
22	**67,073**	**721,979**	**1001**	**88.3**	**2853**	**251.6**	**5778**	**73**	**LEED EB 2.0**	**Silver**	**4/10/09**
23	**205,563**	**2,212,676**	**2420**	**213.4**	**4112**	**362.6**	**30,782**		**LEED CS 1.0 Pilots**	**Platinum**	**5/7/10**
Sum	2,009,494	21,630,195					233,165		LEED-21 (buildings 22 and 23 omitted)		
Bld-wt mean			1108	97.7	2827	249.3		78			
Area-wt mean			1203	106.0	2982	263.0		78			

Banking/Financial in the NYC database rather than office buildings. This match list of NYC LEED-certified office buildings will be referred to as the LEED-21 building set.

3. Results

The LEED-21 commercial office building set consists of 21 buildings with total floor area of 2.01 million m^2 (21.6 million gsf); their characteristics are listed in Table 1. The two additional Banking/Financial buildings (#22 and #23) are listed at the end of Table 1 but are not included in subsequent analysis.[2] Building characteristics listed are total floor area, annual site and (weather adjusted)[3] source EUI, GHG emission, EPR, and the LEED system, level of certification, and certification date. The last three rows of Table 1 contain totals for floor area and GHG emission, and both un-weighted (or building-weighted) and area-weighted site EUI, source EUI, and EPR.

Fig. 1 is a bar graph of the source EUI of these 21 LEED office buildings with bar width chosen to represent the floor area for each building as a percentage of the total area contained in the 21 buildings and color chosen to represent the level of LEED certification – *Gold* (yellow), *Silver* (gray), and *Certified* (green). The area of each rectangle represents the annual source energy (not intensity) associated with each building.

The source EUI for these 21 buildings is given by the ratio of their total source energy to their total floor area and is equal to 2980 MJ/m^2 (263 kBtu/sf). It is equivalent to the area-weighted mean EUI listed at the bottom of Table 1 (see Ref. [9]). This mean EUI is also shown as the dashed red line in Fig. 1. The un-weighted (or building-weighted) mean source EUI of 2830 MJ/m^2 (249 kBtu/sf) is also listed at the bottom of Table 1. This un-weighted mean is easy to calculate but, unlike the area-weighted mean, is not related to the total source energy consumed by the set of buildings. The fact that the area-weighted mean is 6% higher than the un-weighted mean reflects the fact that larger buildings tend to have higher EUI than do smaller buildings. Fig. 1 shows that seven buildings (all *Silver* or *Certified*) have source EUI above the mean while 14 buildings (including all *Gold*) have EUI below the mean.

In previous LEED building energy studies the mean EUI (site or source) of the LEED buildings has been compared with similar figures from CBECS and, based on this comparison, conclusions drawn as to whether the LEED buildings use more or less site or source energy than comparable conventional buildings [2–4,6,7,9–11]. In this case, however, the NYC Benchmarking data set provides measured data for hundreds of similar office buildings for the same year and geographical region.

The NYC Energy Benchmarking public dataset contains EUI data for 1044 large office buildings, comprising a total of 30.17 million m^2 (324,746,000 sf). Manual inspection revealed that some buildings appeared more than once in the database. If, in such cases, one record stood out as credible – the credible record was retained and other records deleted. If a single credible record could not be identified then all records associated with the building were deleted. This process eliminated 42 records. 10 more building records were deleted because their site EUI were so high as to be unbelievable, ranging from 11,740 to 953,000 MJ/m^2 (1035–84,000 kBtu/sf).[4] Finally, 39 additional records with site EUI < 340 MJ/m^2 (30 kBtu/sf) were also eliminated because their EUI were judged to be

[2] ENERGY STAR does not distinguish between Office and Banking/Financial building types. An argument could be made for including them with the 21 LEED office buildings.

[3] The "weather adjusted" source EUI differs from the actual source EUI in that it is adjusted for deviations in the measured HDD and CDD as compared with the 30-year averages. The public NYC benchmark data did not include unadjusted source EUI.

[4] For example, the building with the highest site EUI contains a mere 0.2% of the total floor area but uses 34% of the source energy of all 1044 buildings. Clearly these numbers are incorrect – most likely the result of data entry errors.

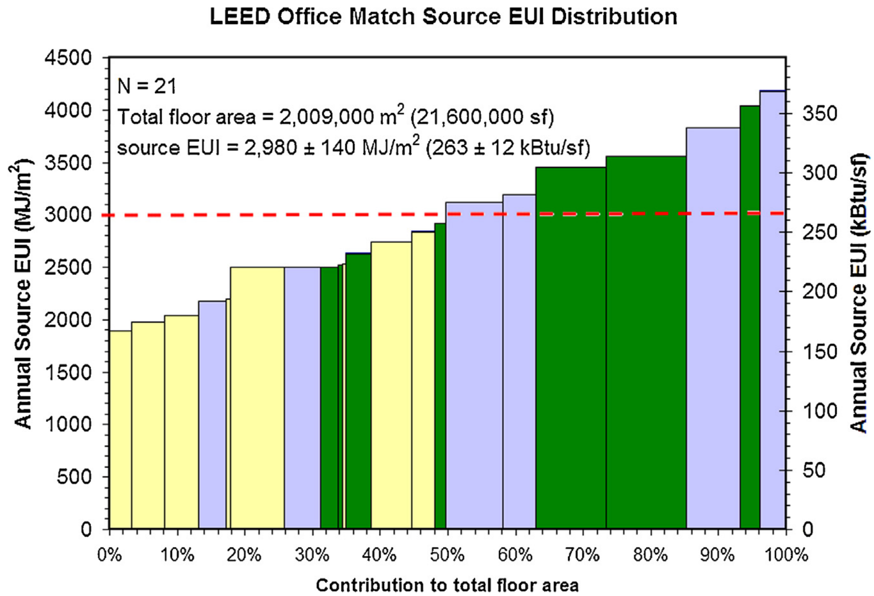

Fig. 1. Each rectangle in this figure represents one of the LEED-21 office buildings. The height of the rectangle is the source EUI and the width represents the floor area of the building as a percentage of the 2.01 million m^2 (21.6 million gsf) for the building set. (For interpretation of the references to color in text, the reader is referred to the web version of the article.)

unreasonably low.[5] The remaining data set contains credible records for 953 office buildings, total area 28,571,000 m^2 (307,545,000 sf) and source EUI equal to 2890 MJ/m^2 (255 kBtu/sf), 3% lower than that of the 21 LEED buildings.[6]

Fig. 2 compares the area-weighted source EUI histogram for the LEED-21 office buildings (plotted up in green) with that for the 953 NYC office buildings (plotted down in red). The area-weighted means for the two histograms are represented by Gaussian curves with widths matching the standard deviations of these means (sdm). The graph confirms that the mean source EUI for the LEED-21 building set is, slightly higher than that for the 953 non-LEED NYC offices. The “overlapping” Gaussian curves indicate that this difference is not statistically significant – namely, the means of the two data sets are too close to resolve given their uncertainties (standard deviation of the mean).[7] In other words, there is no discernable difference in the measured source energy consumed by the LEED-certified office buildings from that consumed by other large NYC office buildings.

While I have argued that the area-weighted source EUI is the appropriate metric for comparing energy consumption for two different building sets, others might wish to compare other EUI. Table 2 lists un-weighted and area-weighted mean site- and source-EUI for various building sets. By any of these four EUI-based metrics we see that the LEED-21 buildings use slightly more energy than do the NYC-953 buildings, the difference ranging from 1 to 7% depending on the metric. In each case, however, this difference is not statistically significant. So, any way you look at it, the energy

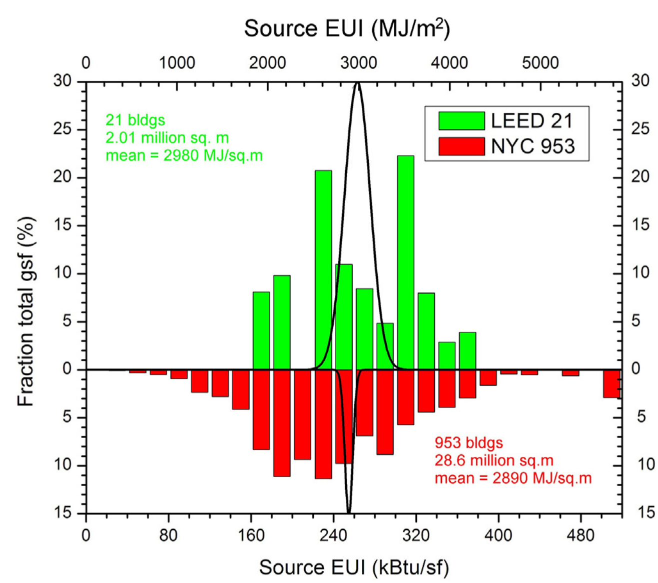

Fig. 2. Source EUI histogram for LEED NYC office buildings (plotted up in green) and all NYC office buildings (plotted down in red). Top axis is labeled in metric units (MJ/m^2) while the bottom axis is labeled in kBtu/sf. EUI are sorted into bins of width 227 MJ/m^2 (20 kBtu/sf). The last bin is for all floor area with EUI > 5670 MJ/m^2 (500 kBtu/sf). (For interpretation of the references to color in text and this figure legend, the reader is referred to the web version of the article.)

used by the LEED-certified office buildings is no different from that used by other NYC office buildings.

The LEED-21 office buildings have also been broken out into subsets by level of certification, *Certified*, *Silver*, and *Gold*. The relevant properties of these building sets are listed in Table 2. Fig. 3 compares the source EUI distributions for the three different levels of LEED certification. A Gaussian distribution is used to represent the source EUI histogram for each certification level with mean and standard deviation chosen to match the means and sdm of the corresponding histograms for the three LEED subsets. A fourth Gaussian (red) represents the 953 NYC office building distribution Table 2 and Fig. 3 show that the LEED *Certified* buildings and LEED *Silver* buildings

[5] A site energy of 340 MJ/m^2 (30 kBtu/sf) for a modern, occupied office building puts it in the running to be a zero energy building (ZEB). A recent ZEB study identified only 30 or so US commercial buildings that fit this description. It is not credible that NYC contains 40-or-so such buildings. More likely they reflect data-entry errors or vacant or nearly vacant buildings.

[6] Dr. David Hsu has performed extensive analysis on the NYC Energy Benchmark data. He used a different statistical process for rejecting statistically high and low source EUI data. His “cleaning” process yielded an office data set with only 811 buildings and a area-weighted mean EUI = 2892 MJ/m^2 (255 kBtu/sf) [15].

[7] The student *T*-test provides a methodology for quantifying this statement. The “*p*-value” for this comparison is 0.55.

Table 2
List of relevant characteristics for various office building sets (see text). Numbers in parentheses are EUI expressed in kBtu/sf.

Office	N		Floor area		Site EUI (MJ/m^2)				Source EUI (MJ/m^2)				EPR	GHG (kg/m^2)
					Building weight		Area weight		Building weight		Area weight			
Building Set	Sample	Total	10^6 m^2	10^6 sf	mean	sdm	mean	sdm	Mean	sdm	Mean	sdm		
LEED-21	21	21	2.009	21.6	1108 (98)	67	1200 (106)	74	2830 (250)	143	2980 (263)	142	78	98
Certified	7	7	0.680	7.32	1270 (112)	137	1470 (129)	130	3090 (272)	210	3330 (294)	166	76–77	116
Silver	6	6	0.694	7.47	1180 (104)	101	1200 (106)	98	3170 (280)	284	3210 (283)	259	75–77	100
Silver+	14	14	1.330	14.31	1030 (91)	62	1070 (94)	66	2700 (238)	177	2800 (247)	178	78–79	89
Gold	8	8	0.636	6.85	920 (81)	52	930 (82)	57	2340 (206)	119	2360 (208)	122	80–82	76
NYC-953	953	953	28.6	308	1100 (97)	23	1170 (103)	19	2630 (230)	44	2894 (255)	43	68–69	93
NYC Office – Hsu	811	811	26.4	284							2892 (255)			95
CBECS	5111	4,620,333	6522	70,203	1110 (97)	22	1050 (93)	15	2540 (224)	50	2400 (211)	32		
CBECS-Off	976	823,805	1134	12,208	905 (80)	22	1050 (93)	25	2170 (191)	49	2610 (231)	52		
CBECS-big-Off	402	36,367	610	6568	1130 (100)	39	1170 (103)	39	2960 (260)	79	2960 (261)	78		
CBECS-Reg	301	200,311	511	5498	1850 (163)	152	1240 (109)	74	3510 (310)	285	2470 (218)	142		
CBECS-Reg-Off	84	58,062	156	1678	980 (86)	98	1120 (98)	95	2080 (184)	231	2640 (233)	236		
CBECS-Reg-big-Off	49	4,114	105	1131	1240 (110)	112	1250 (110)	124	3175 (280)	304	2960 (261)	271		

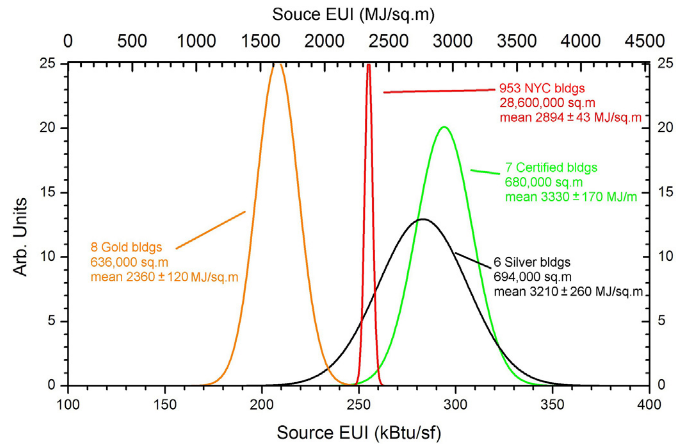

Fig. 3. Normal distributions with mean and standard deviations to match the source EUI histogram means and sdm for *Certified* (green), *Silver* (black), and *Gold* (orange) LEED office buildings, and for the NYC-953 conventional office buildings (red). Metric source EUI units are labeled on the top axis (MJ/m^2) while the bottom axis is labeled in kBtu/sf. (For interpretation of the references to color in text and this figure legend, the reader is referred to the web version of the article.)

use 15% and 11% more source energy, respectively, than do conventional NYC office buildings. In contrast, LEED *Gold* buildings use 18% less source energy than do other large office buildings. The results for *Gold* and *Certified* buildings are significant at the 95% confidence level whereas the *Silver* results are less so (70% confidence level).

The LEED-certified *Silver* and *Gold* buildings were combined to form the *Silver+* set whose properties are listed in Table 2. Various U.S. institutions and governmental bodies have adopted policies that require all future buildings be certified LEED *Silver* or better. We see that the mean source energy for these buildings is 3% lower than that for conventional NYC office buildings – but this difference is not statistically significant.

The NYC Energy Benchmark data set also includes GHG emission for each building. Table 2 lists the GHG emission intensity of the LEED-21 buildings as 98 kg/m^2/yr, just a bit higher than the 95 kg/m^2/yr emitted by the 953 non-LEED buildings. Breaking this down by level of certification we can say with 95% confidence that LEED *Certified* and LEED *Gold* buildings emit 22% more and 20% less GHG, respectively, than conventional buildings. The LEED *Silver* and the *Silver+* buildings emit 6% more and 6% less, respectively, than conventional buildings – but these differences are not statistically significant (i.e., statistically there is no difference between the GHG emitted by *Silver* and *Silver+* as compared with conventional buildings). As expected, the results correlate strongly with those for Source EUI [6].

It is useful to compare the NYC-953 office building set with data from the 2003 CBECS. Table 2 lists the properties from several U.S. building sets extracted from CBECS. These include all U.S. commercial buildings (CBECS), U.S. office buildings (CBECS-Off), big (>4645 m^2 or 50,000 sf) U.S. office buildings (CBECS-big-Off), all regional buildings (CBECS-reg), regional office buildings (CBECS-Reg-Off), and big regional office buildings (CBECS-Reg-big-Off). Regional buildings are restricted to mid-Atlantic census region and climate zones 3 (costal) and 7 (unspecified).[8] The CBECS data show that office buildings tend to have slightly higher source EUI than other commercial buildings, and big office buildings have higher

[8] To maintain confidentiality climate region is not specified for very large buildings 92,903 m^2 (1,000,000 sf) and up in CBECS. Inspection showed these buildings had average HDD and CDD similar to region 3 so they were included. Source EUI were calculated using 3.34 for the site-to-source conversion factor for electric energy to match that used by ENERGY STAR, which is 11% higher than the factor used in Refs. [6,9].

source EUI than smaller office buildings. It is interesting to note that the source EUI for the NYC-953 building set closely matches those for large office buildings in CBECS, both nationally and regionally.

ENERGY STAR *Energy Performance Ratings* or EPR's provide an alternate metric for judging building energy performance. The EPR for each of the LEED-21 buildings is listed in Table 1 and the mean EPR for the LEED-21 and other NYC building subsets are listed in Table 2. As Table 2 shows, the mean EPR for the LEED-21 office buildings is 78, about 10 pts higher than the mean for the NYC-953 buildings (68–69),[9] which itself, is nearly 20 points higher than the presumed mean/median of 50 for all office buildings in the US commercial building stock. This would seem to suggest that the typical large NYC LEED office building is somewhat more energy efficient than the typical large NYC office building which, itself, is much more energy efficient than similar office buildings, nationally. But is there any physical meaning to the "average" EPR for a collection of buildings? And if so, what is the appropriate weighting to be used in calculating this average score? These issues are discussed below.

4. Discussion

The NYC Energy Benchmark data show that LEED certified *Gold* office buildings have about 20% lower source energy consumption and GHG emission than do other NYC office buildings. Both of these savings are statistically significant at the 95% confidence level.

But similar savings are not seen for buildings at the *Certified* or *Silver* levels of LEED certification. These buildings actually consume relatively more source energy and have relatively higher GHG emission than do other NYC office buildings. Collectively LEED office buildings, at all levels of certification or at levels of *Silver or better*, are not significantly different from other large NYC office buildings with regard to source energy consumption and GHG emission. In the first case (all LEED) they are 3% worse and in the second case (*Silver or better*) they are 6% better than conventional buildings. But neither of these differences (+3% or −6%) are statistically significant. The result is consistent with this author's earlier analysis of the NBI LEED data [6,9] and raises serious questions regarding the scientific basis for government and institutional policies, such as New York City's local law 86 that require buildings to be LEED certified in order to reduce GHG emission [16].

And yet ENERGY STAR EPR's, taken at face value, suggest that the LEED-21 office buildings are, in some sense, more energy efficient than the typical NYC office building. How are these conflicting views to be understand?

A possible explanation is that the LEED-21 buildings deliver more "productivity" for the same amount of source energy – perhaps by having longer building hours, higher occupancy density, or housing larger numbers of personal computers[10] – all factors that affect EPR's.[11] EPR's are based on an *energy efficiency ratio* that is defined to be the specific building's source EUI divided by the predicted source EUI of the median US building of similar type, size, climate and operating characteristics [17]. An EPR of 80 (characteristic of LEED *Gold*) yields an energy efficiency ratio of 0.63, indicating such a building uses 37% less source energy than that predicted by *Portfolio Manager* for such a building. Similarly an EPR of 76 (characteristic of LEED *Certified*) implies a source energy savings of 32%. An EPR of 68 (characteristic of NYC Office buildings) implies a source energy savings of 25%. The implication here is that all of these buildings – especially the LEED *Gold*, support more employees and/or operate longer hours and/or have higher densities of personal computers than do conventional U.S. office buildings. If the LEED buildings considered in this study were to operate at a lower productivity (i.e., support shorter hours, fewer employees, etc.) their energy efficiencies would then be reflected in lower source EUI's than other buildings. Instead we see their increased energy efficiency translated into higher performance. There is evidence in the literature that supports higher value and occupancy rates for green buildings [18].

But the above interpretation is built upon key assumptions regarding the credibility of these EPR's. In particular this assumes that the median score for all U.S. Office buildings is 50. This author is not aware of any study that confirms this for today's U.S. commercial building stock. To the contrary, the un-weighted mean EPR for all U.S. buildings whose data have been entered into *Portfolio Manager* is 62 [19]. The mean EPR for all NYC office buildings in this study is 68. A study of 157 California office buildings constructed from 1992 to 1995 found their un-weighted mean EPR to be 64 [20] which, coincidently, is the same as that for the LEED buildings in the NBI study [4]. The USGBC has recently made the claim that their analysis of 195 LEED-certified buildings yielded an average (presumably un-weighted) EPR of 89 [21]. On one level it is conceivable that all of the above building sets represent the upper percentiles of US commercial buildings – clearly this is a goal for LEED – and California has led the country in raising building energy standards. It is also reasonable to expect that office buildings in NYC, one of the most competitive real estate markets, are managed and maintained better than the average US office building. But are these average EPR's to be compared with the presumed national median of 50? Is it possible that the greatly expanded use of ENERGY STAR benchmarking combined with rapid changes in buildings and technology are uncovering some structural problems with the benchmarking tool?

Consider this; CBECS estimates (as of 2003) there are only 337 US buildings greater than 92,903 m^2 (1,000,000 sf) in size. The median EPR for this subgroup is presumed to be 50. The NYC-953 data includes 58 such buildings, with un-weighted mean ENERGY STAR score of 70 and a median of 75. It is statistically improbable that a random sample of 58 of these buildings would yield a mean EPR of 75 if the larger set of 337 buildings has a mean EPR of 50. It would appear that *Energy Performance Ratings* are experiencing "grade-inflation."

Consider the CBECS data upon which the ENERGY STAR theoretical models are based. These data represent building energy consumption from 2003. Much in buildings has changed in the last decade including the significant deployment of efficient lighting and computer technologies. Presumably the entire U.S. building stock is more efficient than it was in 2003.[12] Is *Portfolio Manager*'s regression coefficient for energy used by personal computers appropriate for today's office computers, 2–3 generations removed from 2003? With expanded computer use how important is this single term becoming in the formula for the "predicted source EUI" which is the basis for a building's EPR? Is it even appropriate for

[9] A small fraction of the buildings in each of the two building sets LEED-21 and NYC-953 do not have ENERGY STAR scores; these were omitted in calculating the mean ENERGY STAR score. For the LEED-21 set the area-weighted and un-weighted means were both 78. For the NYC-953 set the un-weighted mean was 68 and the area-weighted mean was 69.

[10] It is clear that longer building hours or more occupants is a sign of higher productivity for a building. But the number of computers is no measure of productivity any more than the number of vending machines or refrigerators. The manner in which ENERGY STAR handles personal computers is unique in that it is the only plug load that raises the predicted EUI on which the EPR is based.

[11] Relevant data were collected for these buildings by Portfolio Manager in rendering these EPR's – but these data have not been released by NYC to the public. NYC has given several academics access to these micro data but this author's efforts to gain access have been unsuccessful.

[12] This does not, of course, mean that today's buildings use any less energy than they did in 2003. Expanded use of technology leads to increased energy consumption even if it is used more efficiently.

ENERGY STAR to increase a building's energy allowance for one particular choice of plug load? Can *Portfolio Manager*'s algorithm be properly applied to buildings over 92,903 m^2 (1,000,000 sf) in size given identified shortcomings of CBECS for such large buildings [22]? It would appear that today's EPR of 75 means that a building uses less source energy than was used by 75% of similar U.S. buildings in 2003 – not 2011.

Also consider the credibility of the building data entered into ENERGY STAR's *Portfolio Manager*. Unlike data gathered for CBECS there is no process for validating data entered into the NYC benchmarking system – evidenced by the outliers identified earlier in the data. While a building's energy purchases are independently verifiable, other factors such as building hours, occupant density, and number of personal computers are not. An EPR for a particular building is easily raised by simply entering larger numbers for building hours and personal computers. These data are not so "well-defined" as purchased energy numbers, providing opportunity for enhancing a building's EPR. With the rapid expansion of use of the ENERGY STAR benchmarking tool both for green-building certification (including but not limited to LEED) and mandated by major U.S. cities, how reliable are the submitted data? Unless the building is seeking ENERGY STAR certification there is no mechanism for independent confirmation of data entered into *Portfolio Manager*. The EPR's for the LEED *Gold* buildings here seem more credible than those for the LEED *Silver* or *Certified* buildings (see Table 1). It is plausible that a greater proportion of the LEED *Gold* buildings have received ENERGY STAR certification, in which case their data entered into *Portfolio Manager* would have been subject to a level of validation.[13]

These ideas are illustrated by considering a specific building – say building #14 from Table 1. This building has an EPR of 75 despite having a source energy EUI of 2926 MJ/m^2 (258 kBtu/sf) – just 1% lower than the CBECS mean of 2960 MJ/m^2 (261 kBtu/sf) for large regional office buildings (see Table 2). Consulting the EPA's technical description of its ENERGY STAR rating for office buildings [23] we see that the EPR of 75 corresponds to a target (i.e., predicted) source EUI of 4253 MJ/m^2 (375 kBtu/sf). We do not know what building operating characteristics lead to this high EPR because key building operating characteristics entered into *Portfolio Manager* – number of workers, weekly operating hours, and number of personal computers – were not disclosed in the public Energy Benchmarking data. Nevertheless, we can see what affect these parameters have on the EPR by using the EPA's *Target Finder* web site [24] and trying different parameters. Entering the EPA's office model mean values for these three variables – 2.07 pc's/100 m^2 (2.23 pc's/1000 sf), 1.63 wkrs/100 m^2 (1.75 wkrs/1000 sf), and 53 h per week we obtain a target source EUI of 2915 MJ/m^2 (257 kBtu/sf) and an EPR of 50–25 pts lower than the building's reported EPR. If we run *Target Finder* again with twice the number of pc's – 4.14 pc's/100 m^2 (4.46 per 1000 sf) – the target EUI is raised to 3346 MJ/m^2 (295 kBtu/sf) and the EPR to 62. If we further increase the weekly hours to 80 the target EUI is raised to 3595 MJ/m^2 (317 kBtu/sf) and EPR to 68. If we now double the number of workers to 1.63 wkrs/100 m^2 (3.5 per 1000 sf) the target source EUI is 3674 MJ/m^2 (324 kBtu/sf) and the EPR 69. So we see that simply changing these input parameters to *Portfolio Manager* changes the target or predicted energy use for the building and accordingly, its calculated EPR.

[13] ENERGY STAR certification requires a site visit and a stamped verification checklist to be completed by a licensed Professional Engineer or Registered Architect. Moreover, the EPA performs additional review and follow-up on applications with unusual data, and EPA also randomly conducts its own independent audits for certain buildings, either by phone or via on-site visits.

This author has petitioned the NYC Mayor's Office to obtain access to the larger Energy Benchmarking data set (including numbers that are not publicly disclosed) to try to better understand the basis for EPR's both for LEED and non-LEED office buildings. While the Mayer's office has made these data available to several academic researchers they have not granted this author such access.

A recent article describing Adobe headquarters discloses that their seven office buildings all have EPR's of 99–100 – yet have site and source EUI of 2030 and 3969 MJ/m^2 (179 and 350 kBtu/sf), respectively – 37% higher than the mean for the NYC office buildings [25]. Such scores are made possible by *Portfolio Manager*'s method for calculating EPR's for mixed-use buildings – in this case, Office buildings that include *Data Centers*. In such cases EPR's are calculated for both spaces independently then combined to form a weighted average for the building with weighting equal to the source energy used by each of the two spaces. Inasmuch as data centers have far higher energy density than office spaces, a data center that occupies a small fraction of the area of an office building may contribute a large fraction of its total energy. Hence the composite EPR for an office building can be dominated by the characteristics of the data center it houses rather than characteristics typically associated with an energy-efficient building. At least in this case this explains the higher than average EPR's for office buildings that have abnormally high EUI.

Setting aside the credibility of the *Energy Performance Ratios* themselves, one still has to ask what do the LEED-21 ENERGY STAR scores tell us about the "value added" by LEED certification? The dominant LEED certification program included here is for Existing Buildings. Presumably these LEED-21 buildings have each undergone extensive renovation in the last few years while, on average, the NYC-953 buildings have not. Any extensive commercial building renovation, LEED-certified or otherwise, will involve cost-effective energy-efficiency upgrades in lighting and HVAC technologies – resulting in a more energy efficient building. The ENERGY STAR scores of the LEED-21 buildings should be compared not with 50, the presumed median for all office buildings, and not with 68, the mean for the NYC-953 buildings, but with the mean ENERGY STAR score of other NYC Office buildings that have recently undergone extensive renovation outside of the LEED certification process. Only then do we see the "value added" of LEED. Simply stating a high average ENERGY STAR score for LEED EB projects provides a clever sound bite, but is otherwise meaningless in providing any indication of "value added" by LEED certification.

5. Summary and conclusions

Here the 2011 energy benchmark data for New York City non-residential buildings, collected as a result of New York City's Local Law 84, are examined and used to understand source energy consumption and greenhouse gas emission by 953 large NYC office buildings. 21 of these buildings were identified as LEED-certified office buildings, allowing us to compare the energy consumption and GHG emission of these LEED buildings with other large NYC office buildings. The results show that, collectively, the LEED buildings use the same amount of source energy and emit the same amount of GHG as do other NYC office buildings. LEED *Gold* buildings show a 20% reduction in source energy consumption and GHG emission than other buildings, but these savings are offset by the fact that LEED buildings at the *Certified* and *Silver* level actually use more energy and emit more GHG than other NYC office buildings. No LEED *Platinum* office buildings were identified in this study. Looking at the LEED buildings that were certified at the level of *Silver or better* we find their GHG emission and source energy consumption to be insignificantly different from non-LEED NYC buildings.

These data provide no evidence that LEED certification, except at the *Gold* level, is moving NYC toward its goal of carbon neutrality.

ENERGY STAR *Energy Performance Ratings* or EPR's for all NYC office buildings averaged 68 while those for the 21 LEED office buildings averaged 78. While there is no clear meaning to the "average" EPR for set of buildings, these averages suggest an energy efficiency that is not confirmed by the measured source EUI. The result raises questions regarding the interpretation and validity of such EPR's. Several possible explanations were proposed, but data presented here are insufficient to resolve these issues. At best it can be concluded that LEED certification has resulted in more efficient buildings (as indicated by EPR's) that neither save energy nor reduce GHG emission – as compared with other large NYC office buildings. These results cast significant doubt regarding the use of ENERGY STAR EPR's as a measure of energy success for LEED-certified buildings. It would appear that the ENERGY STAR benchmarking tool itself requires further validation.

One of the greatest barriers to understanding the efficacy of LEED certification and other energy efficiency measures at reducing building energy consumption and green house gas emission has been the lack of measured energy performance for commercial buildings. The USGBC has been collecting performance data since 2009 for LEED buildings but there is no indication they will make such data public. Energy benchmarking programs in New York and other cities has the potential to dramatically change all this by providing transparency on the energy performance of an unprecedented number of the nation's most advanced buildings. In the next year more energy data will become available from New York City which will allow the list of LEED-certified buildings to be expanded to include those certified in 2011. Presumably similar data from San Francisco and other cities will soon become public further expanding such data. It will be important to see if the results described here are duplicated in other cities or if different results emerge.

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